Task/Subtask IV02.1
CDRL Sequence A014–007
27 January 1995

SOFTWARE TECHNOLOGY FOR ADAPTABLE, RELIABLE SYSTEMS (STARS) PROGRAM

Technical Papers: The Sociology of Megaprogramming: Experiences in Generating an Organizational Learning Enterprise

Contract No. F19628–93–C–0129
Task IV02 – Megaprogramming Transition Support

Prepared for:

Electronic Systems Center
Air Force Materiel Command, USAF
Hanscom AFB, MA 01731–2116

Prepared by:

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	1/27/95	Technical Paper

4. TITLE AND SUBTITLE
The Sociology of Megaprogramming: Experiences in Generating an Organizational Learning Enterprise

5. FUNDING NUMBERS
F19628-93-C-0129

6. AUTHOR(S)
Lynn B. Underhill

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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700 North Frederick Avenue
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8. PERFORMING ORGANIZATION REPORT NUMBER
A014-007

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Electronic Systems Center/ENS
Air Force Materiel Command, USAF
5 Eglin Street, Building 1704
Hanscom Air Force Base, MA 01731-2116

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
N/A

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Cleared for Public Release, Distribution is Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The STARS Program is currently involved in transitioning advanced software engineering technologies into practice within the DoD under the aegis of "megaprogramming". Megaprogramming, which integrates the notions of process-driven, domain specific, reuse based, and supporting automation via a Software Engineering Environment, is intended to enable the formation of product-line organizations with the objective of producing systems "cheaper, better, faster". Tranisitioning to megaprogramming can involved significant changes to existing ways of doing businnes, and to an organization's underlying paradigms. Given the degree of change, sociological forces come into play.

The project that forms the basis of this experience is the SCAI demonstration project, performed by the AF SWSC at Peterson AFB. As a vehicle for organizing the analysis of our project's experience, we will reate it to the disciplines distinguished by Peter Senge in "The Fifth Discipline, the Art and Practice of the Learning Organization". For each discipline, we present our interpretation of our experience, and our recommendations based on our lessons.

14. SUBJECT TERMS
Organizational Learning, Megaprogramming

15. NUMBER OF PAGES
37

16. PRICE CODE
N/A

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

Preface

This document was developed by the Loral Federal Systems - Gaithersburg, located at 700 North Frederick Avenue, Gaithersburg, MD 20879. Questions or comments should be directed to Ms. Lynn Underhill at 719-554-9562 (Internet: underhl@lfs.loral.com).

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Presenter: Lynn B. Underhill
Title: The Sociology of Megaprogramming: Experiences in Generating an Organizational Learning Enterprise
Track: 1 - S/W Process Improvement
Day: Tuesday, April 11
Keywords: Organizational Learning, Megaprogramming

THE SOCIOLOGY OF MEGAPROGRAMMING: EXPERIENCES IN GENERATING AN ORGANIZATIONAL LEARNING ENTERPRISE

1.0 INTRODUCTION

The Software Technology for Adaptable, Reliable Systems (STARS) program is currently involved in transitioning advanced software engineering technologies into practice within the DoD under the aegis of "megaprogramming". Megaprogramming, a strategic intent which integrates the notions of process-driven, domain specific, reuse-based, and supporting automation via a Software Engineering Environment, is intended to enable the formation of product-line organizations with the objective of producing related systems "cheaper, better, faster". Transitioning to megaprogramming can involve significant changes to existing ways of doing business, and to an organization's underlying paradigms. Given the degree of change, sociological forces come into play.

The project that forms the basis of this experience is the Space Command & Control Architectural Infrastructure (SCAI) Demonstration Project, performed by the Air Force Space and Warning Systems Center (SWSC) at Peterson AFB. The project believes that Megaprogramming principals will generate a product-line (family of systems), the creation and maintenance of which will be significantly more efficient and effective than the "stovepipe"[1] software development approaches used today.

As a vehicle for organizing the analysis, our project's experiences will be related through our implicit practice of the disciplines distinguished by Peter Senge in "The Fifth Discipline, the Art and Practice of the Learning Organization". The five disciplines of a learning organization that the SCAI project practiced are: [2]

- *Shared Vision - building a sense of commitment in a group, by developing shared images of the future we seek to create, and the principles and guiding*

1. No intent to share architecture or information except at interfaces.
2. Senge, Peter M., Roberts, Charlotte, Ross, Richard B., Smith, Bryan J. and Kleiner, Art *The Fifth Discipline Fieldbook: Strategies and Tools for Building a Learning Organization.* New York Doubleday 1994 pgs. 6-7.

practices by which we hope to get there.

- *Team Learning - transforming conversational and collective thinking skills, so that groups of people can reliably develop intelligence and ability greater than the sum of the individual members' talents.*

- *Mental Models - reflecting upon, continually clarifying, and improving our internal pictures of the world, and seeing how they shape our actions and decisions.*

- *Personal Mastery - learning to expand our personal capacity to create the results we most desire, and creating an organizational environment, which encourages all its members to develop themselves toward the goals and purposes they choose.*

- *Systems Thinking - a way of thinking about, and a language for describing and understanding, the forces and interrelationships that shape the behavior of systems. This discipline helps us see how to change systems more effectively, and to act more in tune with the larger processes of the natural and economic world.*

It is the premise of this paper that Megaprogramming constitutes what Gary Hammel and C.K. Prahalad would refer to as a "strategic intent". The following quote with give the idea of what is meant by this:

> *"Companies that have risen to global leadership over the past 20 years invariably began with ambitions that were out of proportion to their resources and capabilities, but they created an obsession with winning at all levels of the organization and then sustained that obsession over the 10 to 20 year quest for global leadership. We term this obsession "strategic intent".*
>
> *Gary Hammel and C.K.Prahalad*
> *Harvard Business Review*

The body of the paper presents a very brief overview of historical images of organizations.[1] Peter Senge's framework for organizational learning is then discussed. The SCAI project's implementation of Megaprogramming is discussed in terms of its parallel implementation of the architecture of a learning organization. As a consequence of implementing this architecture, it is the premiss of this paper that the SCAI project has also initiate the cycle of what Peter Senge calls Deep Learning., and can therefore be said to have inadvertently practiced the disciplines of a Learning Organization. For each discipline, we present our interpretation of our experience, and our recommendations based on our lessons.

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1. Morgan, Gareth *Images of Organization*, Sage Publications 1996

2.0 Background

2.1 Organizational Models[1]

To live in an evolutionarly spirit means to engage with full ambition and without any reserve in the structure of the present,
and yet to let go and flow into a new structure when the right time has come.

Erich Jantsch
The Self Organizing Universe

Organizations can be analyzed by comparing them to one of three structures: machines, organisms or brains. Each of these types of organizations can also be viewed as information processing systems. This idea was first introduced by Herbert Simon and his colleagues while he was at Carnegie Institute of Technology (now Carnegie-Mellon University). Simon, viewing organizations like machines, argued that they could never be perfectly rational because their members had only limited information processing abilities. Thus, he argued that individuals and organizations settled for a "bounded rationality" of "good enough" when making decisions, based on simple rules of thumb and limited search for information. He believed that the structure and modes of functioning in an organization limited the rationality of the humans operating within them. [2]

Organizations which function like organisms or brains build organizations based on ecological principals. This allows for the development of structures that support collaboration, within the organization and between the organization and its environment. There is a difference between communication and collaboration. "In a communication-oriented environment, people discuss what they want to do and then go off and do what they think they've agreed upon: in a collaborative environment, people spend people spend as much time understanding what they are doing as actually doing it. Vocabulary is defined precisely; imagery to illustrate idea is agreed upon; individuals generate shared understanding that they couldn't possibly have achieved otherwise."[3] These types of organizations are influenced by their environment and can take an active role in shaping their own future.

The higher the degree of change within the environment the greater is the need for a "substantially sustainable" rational organization (as opposed to basing decisions on the bounded rationality of good enough). Substainable rationality requires that an organization be able to question the appropriateness of what they are doing, modify their actions to take into account changes in their environment, and take actions that manifest intelligence in relationship to their environment. The brain stands supreme among all natural and man made systems as a system for initiating intelligent action. The key distinction between thinking about an organization as an organism versus a brain is that organizations thought of as organisms, have a brain which organi-

1. Almost all of the information in this section is derived in whole or in part from Gareth Morgan's book *"Images of Organization"*.
2. Morgan, Gareth *Images of Organization*. Newbury Park, California SAGE Publication, Inc. pg. 81
3. Schrage, Michael *Shared Minds, The New technologies of Collaboration*, Random House 1990, pg 31-32

zations thought of as brains function ***as if they were brains.*** [1] In organizations thought of as organisms some central part of the organization is responsible for planning, strategy, and developing information networks. Organizations which function as brains are also holographic.[2] The ability to learn is the aspect of these types of organizations which is of interest.

Organizations that function as brains are also systems that have learned to learn. They are also referred to as double loop learning systems. Several barriers to this type of learning exist in most of today's organizations. They include:[3]

- Bureaucratic approaches to organization that impose fragmented structures of thought on members giving them little to no access to a whole picture of the organization's total situation.

- Approaches to accountability which reward success and punish failures, encouraging various forms of deceit and defensiveness. Such organizations can tolerate very little uncertainty and have a tendency to want to tie things down, stay on top of things and address only those problems that appear solvable.

- Major gaps between what people say and what they do. There is a gulf between the theory and reality of what people are doing. People tend to meet problems with rhetoric to convey the impression that they know what they are doing. People tend to engage in diversionary behavior, and place blame elsewhere rather than questioning the assumptions and behaviors that they engaged in to produce those results. People develop groupthinks and mindsets which are very difficult to break and prevent them from understanding and dealing with their problems.

Examples of what prevents double loop learning also point to how to encourage it. In essence it requires an new philosophy of management that roots the process of organizing into a process of open-ended inquiry, allowing for the ability to question operating assumptions in a fundamental way. The following guidelines summarize how to initiate and manage a learning - oriented approach.[4]

- Encourage and value openness and reflectivity so that you accept error and uncertainty as an inevitable feature of complex and changing environments.

- Recognize the importance of exploring different viewpoints when analyzing

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1. Morgan, Gareth *Images of Organization*, Newbury Park, California SAGE Publishing, pg 79
2. Holography creates images, where the whole of the image is contained in each of the parts. If the picture is broken, a piece of the picture can be used to create the whole image. Neuroscientist Karl Pribram suggest, that the brain functions according to holographic principles, and we are interested in designing learning organizations that adhere to holographic principles.
3. Ibid., pgs.89-91
4. Morgan, Gareth, *Images of Organization*, Newbury Park, California SAGE Publishing, pgs 91-95

and solving complex problems.

- Avoid imposing structures of action upon organized settings. Have action be inquiry-driven.

- Create organizational structures and processes that help implement the above principles.

Holographic organizations are composed of operational teams that have complete responsibility for the production of their product or service. Each employee on the team is capable of performing multiple tasks required in producing the product. The teams meet daily to make decisions about production, how to divide work, attend to special issues or concerns regarding the product design, or the hiring of new employees. Members of the team are responsible for setting their own hours of work, schedules, and conduct their own quality control. Each team has a leader who acts as a resource, coach, and facilitator.

Additional administrative and technical teams provide support systems, services, and materials. These teams play an important function in helping the operating teams to integrate new ideas, products, processes and equipment into daily operations. Employees are bound together by their common endeavor through training and orientation programs, which help them build a common vision, values and a shared sense of mission and purpose. Rigorous pre-design of processes and close control of work give way to more experimental learning through action processes that emphasize self management. Organizational coherence is built by creating a shared sense of the corporate whole in each and every individual. This is the kind of organization that megaprogramming creates and supports.

2.2 Framework for Organizational Learning [1]

Several aspects of a learning organization are addressed and their relationships are depicted in Figure 1. Peter Senge refers to these aspects as the "Domain of Enduring Change" or the deep learning cycle, the "Domain of Action" or the architecture of a learning organization, the "Implicit Generative Order", and the "Results". The structure depicted in Figure 1, will be referred to as the Organizational Learning Framework. You will notice that the word Domain is not reproduced in the Framework in Figure 1. This is done because of Megaprogrammings use of the word Domain which both extends and refines the general use of the term. To avoid confusion the general term used by Senge has been replaced with the term "sphere".

Senge doesn't say much about the "Implicit Generative Order" (upper right of Figure 1). It appears that "implicit generative order" is what Hammel and Prahalad refer to as "strategic

1. Many ideas in this section are taken in whole or in part from an article by Peter Senge in *The Fifth Discipline Fieldbook* called *Moving Forward - Thinking Strategically about Building Learning Organizations.*

intent". As the strategic intent of an organization is an idea, to be achieved it is by its very nature implicit. To become explicit action must be taken to generate it. "Results" are produced as a consequence of implementing the "architecture" defined in the Organizational Learning Framework to generate the idea. Results allow the organization to determine if the intent has been achieved. Results when analyzed in relationship to the strategic intent can provide deltas which are then used along with the strategic intent to source or generate a new implementation of the intent and of learning. The next iteration of generating will also use the deltas to refine the architecture and improve the organizations accuracy in achieving the strategic intent.

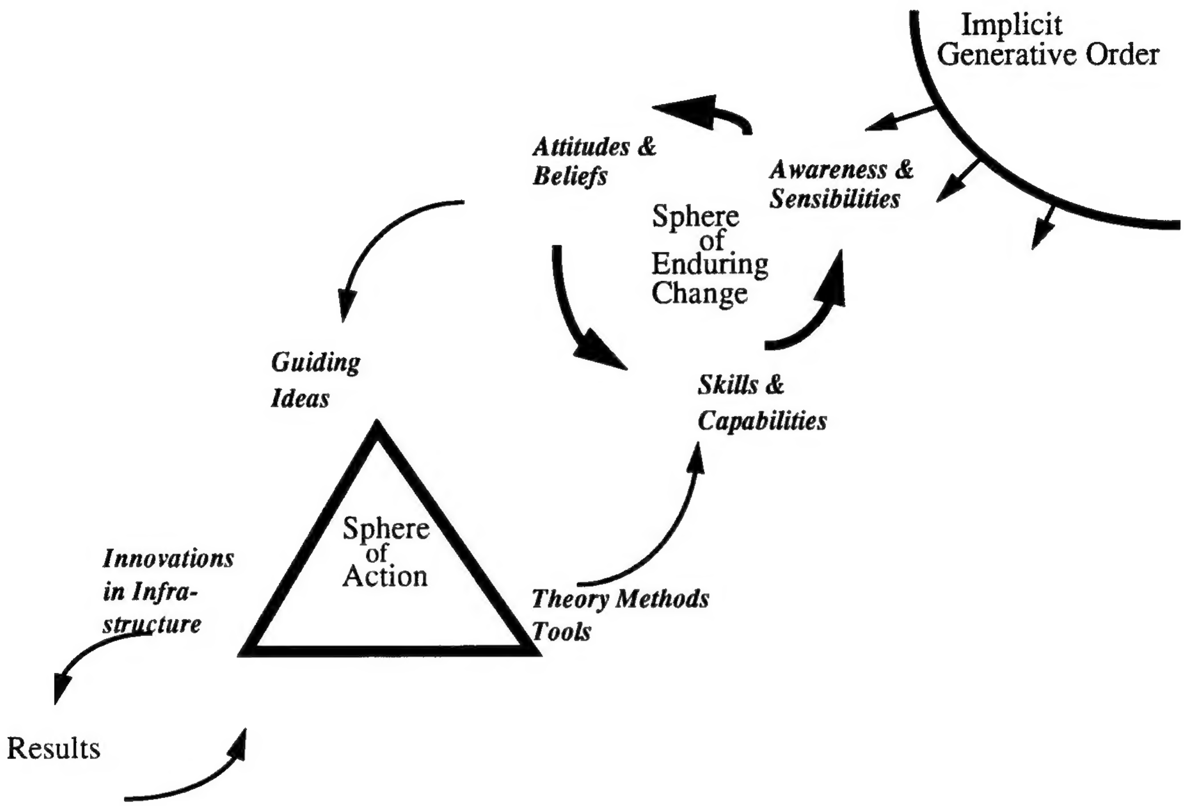

Figure 1. Organizational Learning Framework

To achieve Enduring Change, team members develop new skills and capabilities which alter what they can do and understand. As these capabilities are developed, members develop new awarenesses and sensibilities about the environment in which they reside. Over time this leads to people seeing and experiencing the world differently, creating new beliefs and assumptions. This enables further development of skills and capabilities. The five basic learning disciplines are the means by which the deep learning cycle is activated and sustained.

The "Sphere of Action" is defined by the relationships between guiding ideas, innovations in infrastructure, and theory, methods and tools. Actions taken in this sphere produce an organization's results, such as products, processes, etc. When there are significant changes in an organization's actions in the three areas identified above, the effects of changes in this sphere

can cause a precessional effect[1] that generates the initiation of the deep learning cycle. This will cause enduring changes to occur within the organization.

A most important aspect within this framework concerns the relationship between the Sphere of Enduring Change and the Sphere of Action. Changes in the Sphere of Enduring Change are often what really matter to an organization, however to obtain them attention is best placed on the Sphere of Action depicted by the triangle. The triangle represents the sphere of operational changes where concentrated time and energy produce results.

In many organizations, it may appear that nothing but the activity in the triangle is occurring, for a very long time. People talk about new ideas, practice the application of new tools, and implement changes in the infrastructure. Deeper changes are in the offing, but even as they start to become evident, many will not even notice them.

It is a hypothesis of this paper that megaprogramming as implemented on the SCAI project caused our organization to undergo changes (the primary movements) in The Sphere of Action represented by each of the vertices of the triangle, and as a result we have begun to implicitly activate the precessional movement of the deep learning cycle which is symbolized by the circular motions depicted in the Sphere of Enduring Change.

3.0 Learning Disciplines and SCAI Project Experience

If you always do what you always did
you will always get what you always got.
Shelby Bishop (at 8 years of age)
giving advice to her Mom

Demonstration Project Background[2]

Despite DoD attempts to curtail soaring software development and maintenance costs, the cost of supporting mission software for United States Space Command (USSPACECOM), North American Aerospace Defense Command (NORAD) and Air Force Space Command (AFSPC) continues to rise. The AFSPC Space and Warning Systems Center (SWSC) is responsible for the maintenance and evolution of mission-critical software meeting operational requirements for NORAD, USSPACECOM and AFSPC for the command and control centers, as depicted in Figure 2 for the Cheyenne Mountain Air Force Station (CMAS). These command and control centers are responsible for national attack warning/assessment and space surveillance/defense/control. In addition to direct software support, the SWSC provides network software engineering, configuration management, security and technical support for communica-

1. Refers to the movement in a secondary system, caused by movement in a primary system, for instance the effects of the combined forces of the planets in producing precession of the equinoxes.
2. For more information please refer to the AF/STARS Demonstration Project Experience Report.

tions, and space and warning systems. AFSPC is interested in applying new software technologies to realize lower maintenance costs and improve quality and reliability.

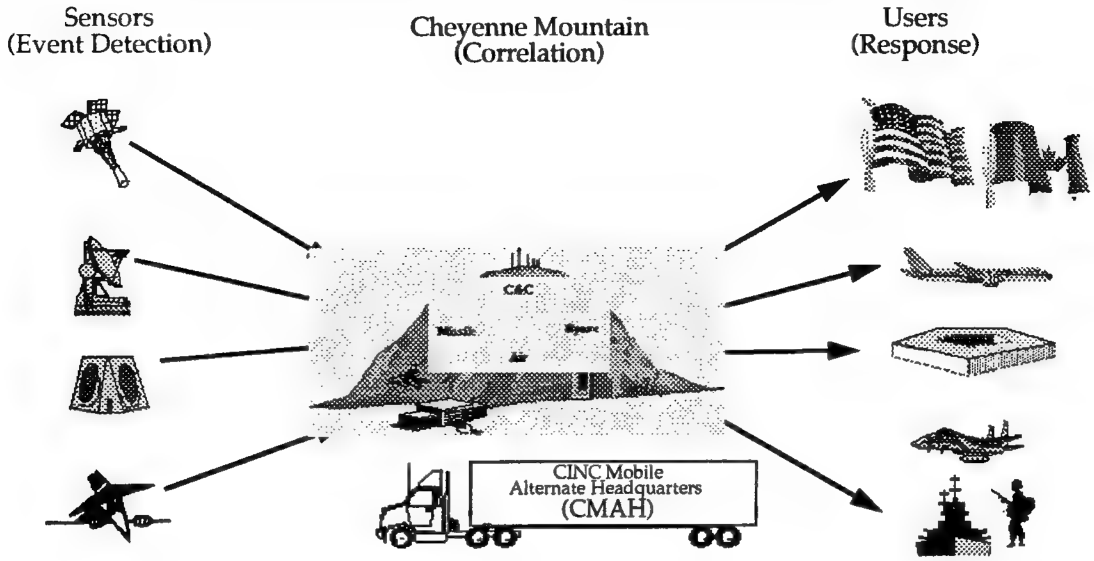

Figure 2. CMAS Systems

The AFSPC legacy predates the recognition of the importance of a disciplined software engineering process. Stovepipe implementations have precluded reuse. Diverse tools and methods have precluded resource sharing. Single system-oriented organizations have precluded the transfer of technologies. AFSPC currently maintains in excess of 12 million lines of code on 34 separate operational systems written in 27 languages. These stovepipe software implementations are a natural product of the bureaucratic hierarchies they were designed to support and these hierarchies' reflected state of the art organizational design in the time frame they originated.

In 1990 the AFSPC SWSC initiated an effort to develop a strategy to move to an architecture based on Open Systems Environments as quickly as possible. While the SWSC usually inherits systems procured through Electronic Systems Center (ESC), in some cases, on an experimental basis, the SWSC has attempted to perform some new development itself. As a result of one of these experiments, the SWSC, in cooperation with TRW, set about to demonstrate large scale reuse. They developed a set of architectural components, called the Command and Control Architecture Infrastructure (C^2AI), that promise to significantly reduce systems development time and cost while increasing quality.

The concept for the C^2AI was developed in the SWSC as a result of analyzing the systems that the SWSC is responsible for. Leveraging work accomplished by TRW on a production contract called CCPDS-R (Command Center Processing and Display System Replacement), the SWSC contracted TRW to advance CCPDS-R techniques and to demonstrate a subset of the Cheyenne Mountain Missile Warning requirements, on a pilot program called the Reusable Integrated Command Center (RICC).

The RICC technology, developed for the SWSC by TRW under the Air Force Embedded

Computer Resource Support Improvement Program (ESIP) in 1991, yielded the first set of reusable artifacts supporting a new common architectural approach including tools for generating Ada code and definition files for an application, plus the domain reusable components.

In mid 1992, AFSPC's interest in applying new software technologies to realize lower maintenance costs and improve quality and reliability lead them to identify the Space Command and Control Architectural Infrastructure (SCAI) project as a strong candidate for Advanced Research Projects Agency (ARPA) and Air Force consideration for the Software Technology for Adaptable, Reliable Systems (STARS) Program. In 1993 ARPA executed a Memorandum of Agreement (MOA) committing both sides to collaborate in addressing their mutual objectives. Loral, one of the STARS prime contractors, began working with the SWSC and its contractors to understand the SWSC domain and its processes, and to provide early coaching on relevant STARS ideas. The SCAI demonstration project is tasked with developing and demonstrating megaprogramming approaches to creating software that are "cheaper, better, and faster" than most practices that are currently in use today.

SCAI Megaprogramming Results

The first release of a C^2AI system using the Megaprogramming Product Line development approach has produced the results outlined in Figure 3. Several organizations collaborated to produce these results or the technology supported, process-driven, domain specific, reuse-based environment in which they were produced.

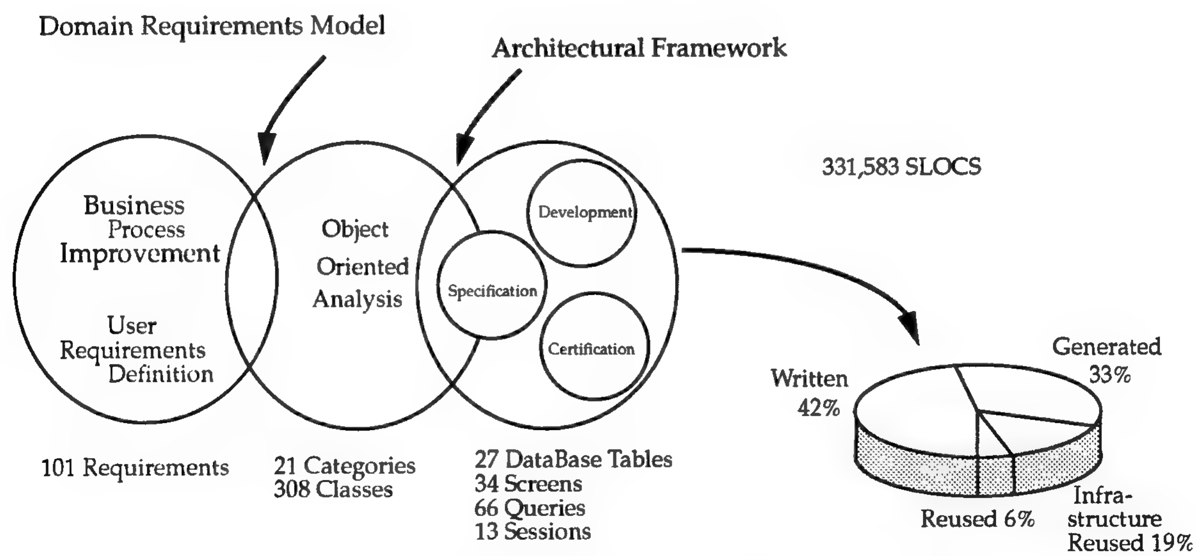

Figure 3. First Megaprogramming Results

As mentioned earlier, the three aspects inherent to megaprogramming software develop-

ment environment (process-driven, domain specific, reuse-based and technology supported via an automated SEE,) map to the three vertices (innovations in infrastructure, guiding ideas and theory methods tools), which compose the Sphere of Action or the architecture of a learning organization (Figure 4.) The organizations participating in the SCAI project (Air Force Space Command/Space and Warning Systems Center, CACI, ccPE, Kaman Sciences Corp, Loral Federal Systems, PRC, Rational, Robbins-Gioia, SEI, SET, and TRW) intended to demonstrate the benefits of using megaprogramming (better, cheaper, faster). This paper proposed that the three aspects of megaprogramming map to Senge's Architecture for Organizational Learning (Sphere of Action), so they can also be said to have inadvertently instantiated the deep learning cycle of the Sphere of Enduring Change.

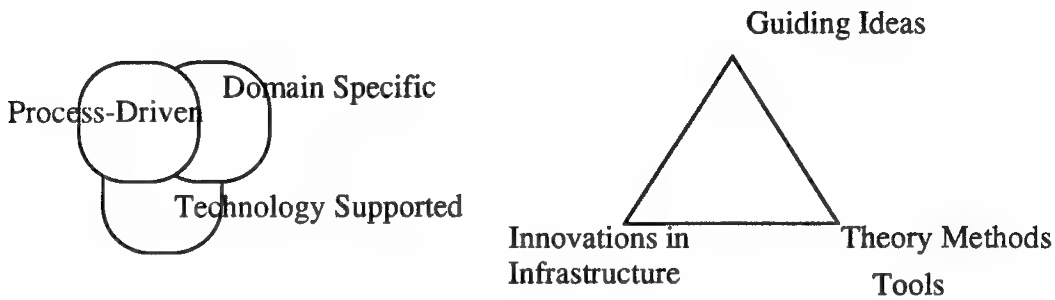

Figure 4. Mappings Between Megaprogramming and Senge's Architecture

The interplay between adopting new guiding ideas, developing innovations in infrastructure, using new theories, methods and tools has resulted in the implicit use of some of the five learning disciplines. The remainder of the paper will discuss how the SCAI experiences with creating change through the conscious effort to transition technology, has lead the demo project to the "unconscious" practice of the five disciplines. The discipline definitions are repeated below for convenience. Each of the disciplines is discussed separately, but in most if not all cases, multiple disciplines are interacting to produce the results described.

- *Shared Vision - building a sense of commitment in a group, by developing shared images of the future we seek to create, and the principles and guiding practices by which we hope to get there.*

- *Team Learning - transforming conversational and collective thinking skills, so that groups of people can reliably develop intelligence and ability greater than the sum of the individual members' talents.*

- *Mental Models - reflecting upon, continually clarifying, and improving our internal pictures of the world, and seeing how they shape our actions and decisions.*

- *Personal Mastery - learning to expand our personal capacity to create the results we most desire, and creating an organizational environment, which encourages all its members to develop themselves toward the goals and*

purposes they choose.

- *Systems Thinking - a way of thinking about, and a language for describing and understanding, the forces and interrelationships that shape the behavior of systems. This discipline helps us see how to change systems more effectively, and to act more in tune with the larger processes of the natural and economic world.*

3.1 Shared Vision

Shared Vision refers to building a sense of commitment in a group, by developing shared images of the future they seek to create, and the principles and guiding practices by which they hope to get there. Megaprogramming provides a road map by articulating a strategic intent and by providing principles and guiding practices to produce the product line development future sought by many organizations. It is a product line (family of systems) approach to the creation and maintenance of software intensive systems and is characterized by the reuse of software life-cycle assets within a product-line including common architecture and components. Megaprogramming also includes the definition and enactment of disciplined processes for the development of applications within the product-line and for the development and evolution of the product-line itself.[1] It is seen as the vehicle for enabling a future product line organizations by making it possible for these organizations to develop and manage many systems within the

1. Abstracted from *STARS Program History, 1983-1993, Version 1.1*, assimilated by Joel Trimble.

domain of their applications, cheaper, better and faster.

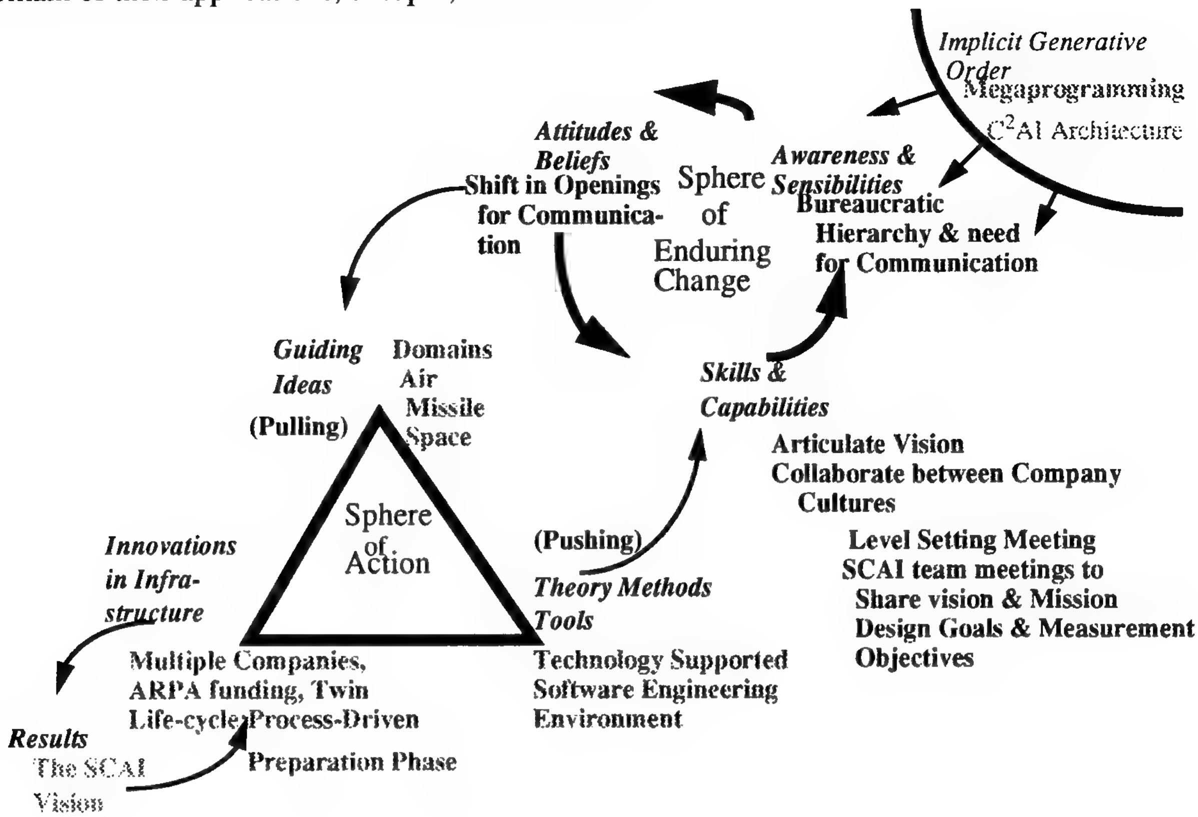

Figure 5. Developing a Shared SCAI Vision

Implementing Megaprogramming continuously provides the opportunity to create shared vision on the SCAI project. This vision is also beginning to be shared by the SCAI project with elements of a larger Department of Defense community. The project has gone through various stages in developing the shared vision, and the vision is shared by participants to varying degrees.

The project is developing a *shared* vision because although the principles of megaprogramming had been articulated, the practice of megaprogramming to a large extent had not. The Air Force had practiced aspects of Megaprogramming, creating the architectural infrastructure discussed earlier. As a consequence the project has been able to participate in developing the shared vision through determining and articulating what the principles of the strategic intent mean in practice.

When relating SCAI experience to the Organizational Learning Framework depicted in Figure 5, the "Implicit Generative Order" (upper right hand corner) sourcing the creation of the project's shared vision could be said to be provided by the relationship that is created between the principle aspects of the megaprogramming paradigm. The domain specific reuse aspect of the megaprogramming paradigm can be interpreted as providing the guiding ideas which support the emerging views of SWSC responsibilities in terms of domains, supported by a common

architectural infrastructure, created and maintained using technology supported process driven development techniques.

The domain specific, reuse based guiding idea was in turn supported by a megaprogramming infrastructural process known as the Twin Life-cycle Development Process. The SCAI project almost immediately participated in the re-engineering of this process to have application engineering more clearly related to domain engineering with both disciplines occurring simultaneously, rather than having domain engineering drive application engineering. Another key innovation in infrastructure was available to the SCAI project as a result of the way STARS structured the project schedule and funding resources into phases. The initial project phase, known as the Preparation Phase, lasted a year, and was designed to allow the project participants to prepare the processes and technologies they would use during the Performance Phase.

Early in the project a "level setting" meeting was held to introduce the megaprogramming principles to the multiple organizations participating on the project. Movement in developing a shared vision was much slower than anticipated. The ideas of developing product lines based on domains kept pulling (as depicted in the Organizational Learning Framework, Figure 5) and each organization began to realize that if they were going to be able to collaborate on developing a SCAI Application/Domain Engineering process we would have to develop ways to enhance the flow of communications between organizations. The SCAI team began to explore avenues of co-locating team members and establishing computer communication links where possible.

At the same time, each organization began providing classes (described under team learning) on their approaches to software development or process definition technology. Some project members began focusing on the articulation of the project vision, mission, and goals, and on getting team members to focus on how the project would measure success in meeting the goals and objectives. This team held a series of meetings with each of the key project areas (comprised of members from the different project organizations) to develop concurrence.

As the team began learning about each other's methods and tools, and focusing on what the SCAI project team was trying to accomplish, there was an observable increase in the sense of a shared project vision. This was demonstrated by project concurrence on a AE/DE process and a process definition approach.

The sense of shared vision and purpose continues to evolve as the "software release", "process-driven" and "SEE" results of practicing the SCAI approach to megaprogramming are available, and as the project takes the opportunity to reflect on and share our experiences with other organizations.

3.2 Team Learning

Team Learning refers to the ability to transform conversational and collective thinking skills, so that groups of people can reliably develop intelligence and ability greater than the sum of the individual member's talents. Our first Team Learning example illustrates that the triangle depicting the Sphere of Actions, really rotates, showing that all the vertices push and pull to acti-

vate the deep learning cycle of the Sphere of Enduring Change (see Figure 6). This process of the team learning also impacted the project's facility in creating our shared vision of megaprogramming.

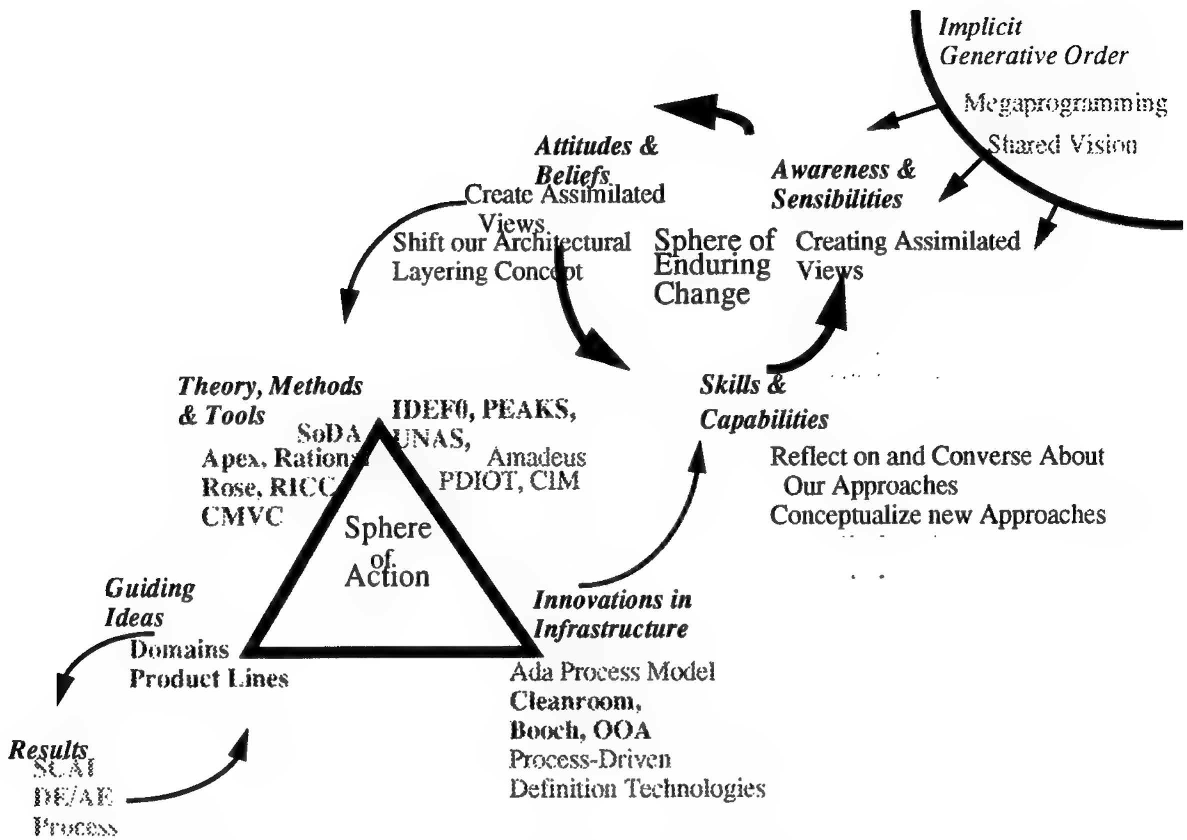

Figure 6. An Example of Team Learning on the SCAI Project

In many respects, the Loral STARS team expected to find a new canvas, on which they would work with project participants to guide them in designing a process-driven Domain and Application Engineering Process. What was found instead was a fairly well painted canvas with each organization having well developed ideas and project histories which pointed to "best practices".

For many months it seemed that the project would never get past each organization's belief that their way of doing business, or their proposed technology, was the proper way for the SCAI project to implement an aspect of the megaprogramming paradigm. For some, the object oriented approaches for analyzing and depicting the domain seemed opposed to the structured analysis approaches imbedded in the Ada Process Model and the Cleanroom Development Process. The $IDEF_0$ process definition technologies, in common use throughout the DoD community, appeared to lack information needed for enacting processes.

Finally as classes and discussions were held, allowing each organization to teach the

other team members their use of methods and tools, all team members began to realize that to demonstrate megaprogramming they had to collaborate. A layered architectural concept began to emerge that allowed use of different methodologies for designing code in different layers of the architecture, incorporating the best aspects of OO and Structure Analysis. The discussion regarding the limits of $IDEF_0$ lead to a better understanding of what was needed for process definition.

At some point each team member began to observe and question their approach in light of the different perspectives they were learning. They also began to realize the advantages of teaming with other organizations to co-create new practices that incorporated the best of each organizations' original approach. For more details on the SCAI DE/AE approach and its development please refer to Appendix E of the AF/STARS Demonstration Project Experience Report.

As individuals began learning about the others' methods and tools, while focusing on what the SCAI project team was trying to accomplish, there was an observable increase in the project energy and creativity. The process of building the SCAI DE/AE process, the approach that the team would use to implement megaprogramming in developing operational command and control systems, began to be developed. People began finding creative ways to combine the multiple technologies and overcome obstacles.

Another example of team learning on the SCAI project involves the process of defining the Walkthrough Inspection Process used by software developers. This process has been defined by the software development team lead, and is an application engineering development process. On the SCAI project the DE/AE processes are primarily defined for the specification, design and development of our software applications and for abstracting the results to define our domain models. The application engineering processes have been initially defined to support manual enactment since the capabilities to support automated enactment of processes were not ready in the expected timeframes.

The SCAI project used $IDEF_0$ in combination with Process Definition Information Organizer Templates (PDIOT) to specify a static view of a process at a functional level, in terms of the actions/tasks that need to be performed in a prescribed sequence. This combination of technologies allowed process definers to collect all the information needed to depict a process that can be either manually or automatically enacted.

What the project has observed happening, at least in the instance of the Walkthrough Inspection Process, is that the performers of software development have re-depicted the manually enactable process they follow on a daily basis. It is now in the form of a state transition diagram. This depiction identifies what is required of a code product to transition into or out of any process state. The actions or task performed by the developer while their product is in a particular state are left up to the discretion and training of the developer. The team members love their newly defined process. It is depicted on a single page. It enables the team lead to communicate easily to team members the work to be done, and to determine where in the overall software development process anyone is. Re-depicting the process enhanced the degree of ownership that team felt for their processes.

One member initially reported that he thought defining processes was a waste of time. The schedules that he had developed based on his established approach to software design and development, had temporarily lost all accuracy because of the time being taken to define the process used, and learn the new process development methodologies. He now believes the effort entailed in process definition was well worth it. Schedules are now created in relationship to the defined process. Also team members not trained in astro-physics can follow the process and produce software that gives results with the same accuracy as today's systems, without hours and hours of debugging.

The team learning that has taken place here is an example of the kind of learning talked about when organizations function as brains. What has happened is that the software development application engineering team has adopted a new function, that of defining their own processes. They learned from process engineers about what is required to have a defined enactable process, and then adapted a dynamic depiction of their process that worked in their environment. This process depiction is also influenced by the system analysis/thinking techniques they utilize on a day to day basis to abstract and design the software system they build.

3.3 Mental Models

A third discipline of a learning organization is the ability to continuously confront what Peter Senge calls "mental models". Mental models are deeply ingrained assumptions, generalizations, or images. These are usually a result of our interpretations of some past event. The assumptions influence how we understand what is happening in the world and how we take action to respond. When these interpretations are held by individuals we call them mental models, when held by organizations or societies we generally refer to them as paradigms. The insidious thing about them is that for the most part it never occurs to people that they are operating within them. Uncovering them provides real access to personal empowerment and thus organizational empowerment.

The ability to listen for the kind of feedback that gives access to uncovering mental models allows one to regulate his/her behavior, to conform to the "rules and regulations", and also to evaluate the assumptions that give rise to those interpretations. This reflective ability allows one to evaluate if a given response still makes sense in a changing environment. This ability is what characterizes "substainably rational" double loop learning systems.

Organizational systems are made up of organizational processes, which are either explicitly or implicitly defined. Processes provide a framework for the actions through which visions are made real (or not). Undefined processes hinder an organization's ability to respond optimally, because the full range of options available to individuals when the processes are visible, are usually hidden when processes are undefined. Defining organizational processes provides an opportunity for a collaborative effort which generates a knowledge base that belongs to the entire organization. Defined processes can provide a common ground so that actions can be collectively owned, consequences of actions observed across the system and processes improved. Process improvement opportunities can be identified by more people, because more people are aware of or know the process.

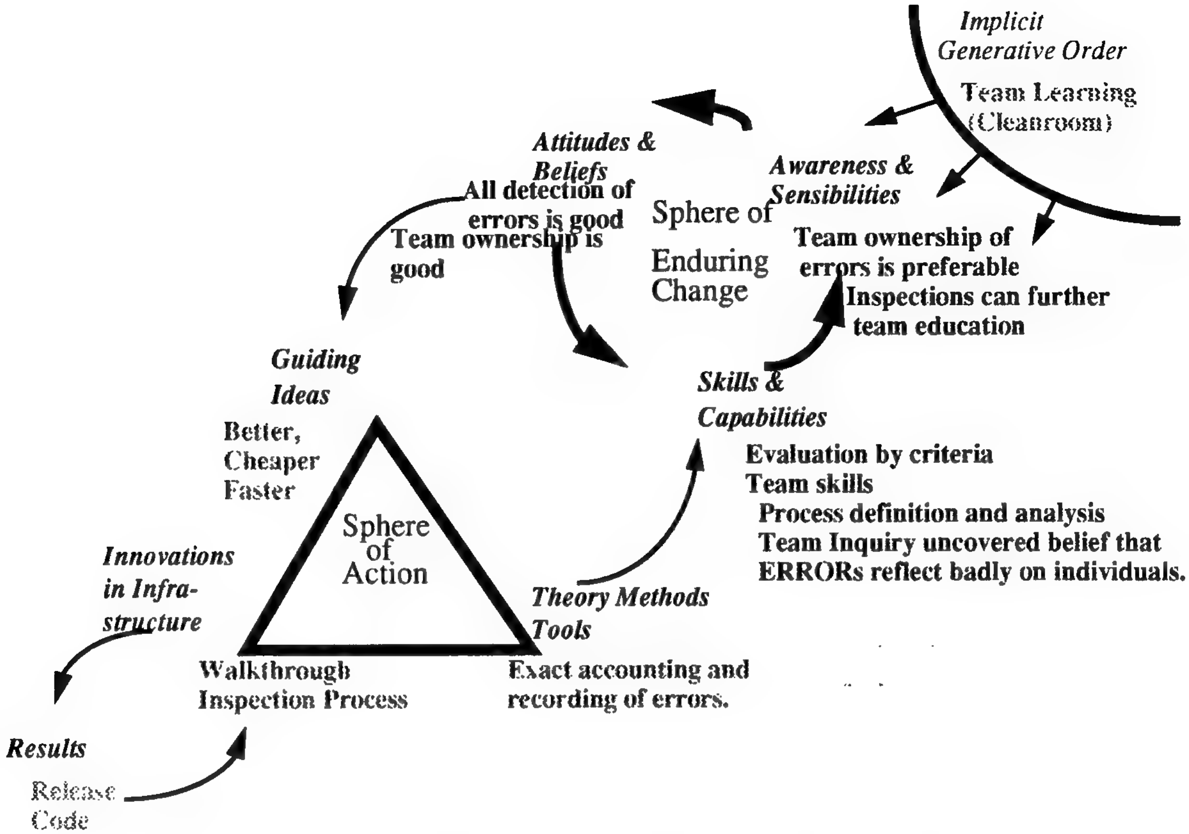

Figure 7. Uncovering Mental Models on the SCAI Project

One instance of uncovering a mental model on the SCAI project was demonstrated by the software development team which was using a Walkthrough Inspection Process. This process is impacted by the Cleanroom development methodology and provides an innovation to the infrastructure (see Figure 7). This process defines software development in terms of the states a piece of software generally goes through from software specification through its delivery to the test organization. Each state is defined by the inputs required to begin work in that state, and the criteria that the product must meet prior to transitioning to the next logical state. A team inspection of the product is held prior to each transition from a occupied state. The product is evaluated against criteria, and defects are recorded.

The process impacted the team's method of recording errors, by requiring an exact account and recording of those errors. Team members, as a result of these changes, are learning how to evaluate products against pre-defined criteria, and how to evolve criteria as a result of process improvements. What the team lead noticed by having a defined process, was that team members initially demonstrated a reluctance to record all errors. This caused him to question whether there might also be a "hidden" reluctance to identify errors.

He began discussions with team members where he pointed out that certain kinds of

errors were not being documented early in the inspection process. The team began an inquiry into what was happening. It turned out that team members believed that having errors was bad and reflected poorly on the individual whose code was being inspected. As the inquiry proceeded the team saw the impact this kind of belief could have on their team delivered products, and decided to assume ownership of each product at its first inspection. The idea of team ownership is also characteristic of cleanroom development methods. It was decided that errors found late in the Walkthrough Inspection Process reflected badly on the team. When errors were found early in the process, opportunities were taken for team members to instruct one another.

Uncovering mental models, as can be seen by this example, facilitates team learning.

3.4 Personal Mastery

Personal Mastery is defined by Senge as learning to expand our personal capacity to create the results we most desire, and as creating an organizational environment which encourages all its members to develop themselves toward the goals and purposes they choose. This definition for the most part, does not really fit very well into an environment composed of multiple contractors or companies, because there are so many regulations governing how contractors and their administrators must behave. On the SCAI project this impacts how the government can interact with contractors, and how those contractors can interact with their subcontractors.

However, we think that the SCAI project meets the intent of Personal Mastery, if we assume that most individuals who are working on this program are doing so because, to some extent, the work here maps to their personal interests. To the extent that this is true, the project has provided people with many opportunities to learn new ideas and concepts and expand their personal capacity.

The SCAI project is a project that is driven by ideas of transitioning technology, both onto the project, and then out to the SWSC organization, and to other DoD Software development organizations (see Figure 8). STARS' recognition of this reality caused it to support innovations in infrastructure that included both a Project Preparation Phase, and a Project Reflection Phase. Both phases on the project encourage people to learn, and to adjust transitioning processes and procedures to reflect the results of that learning.

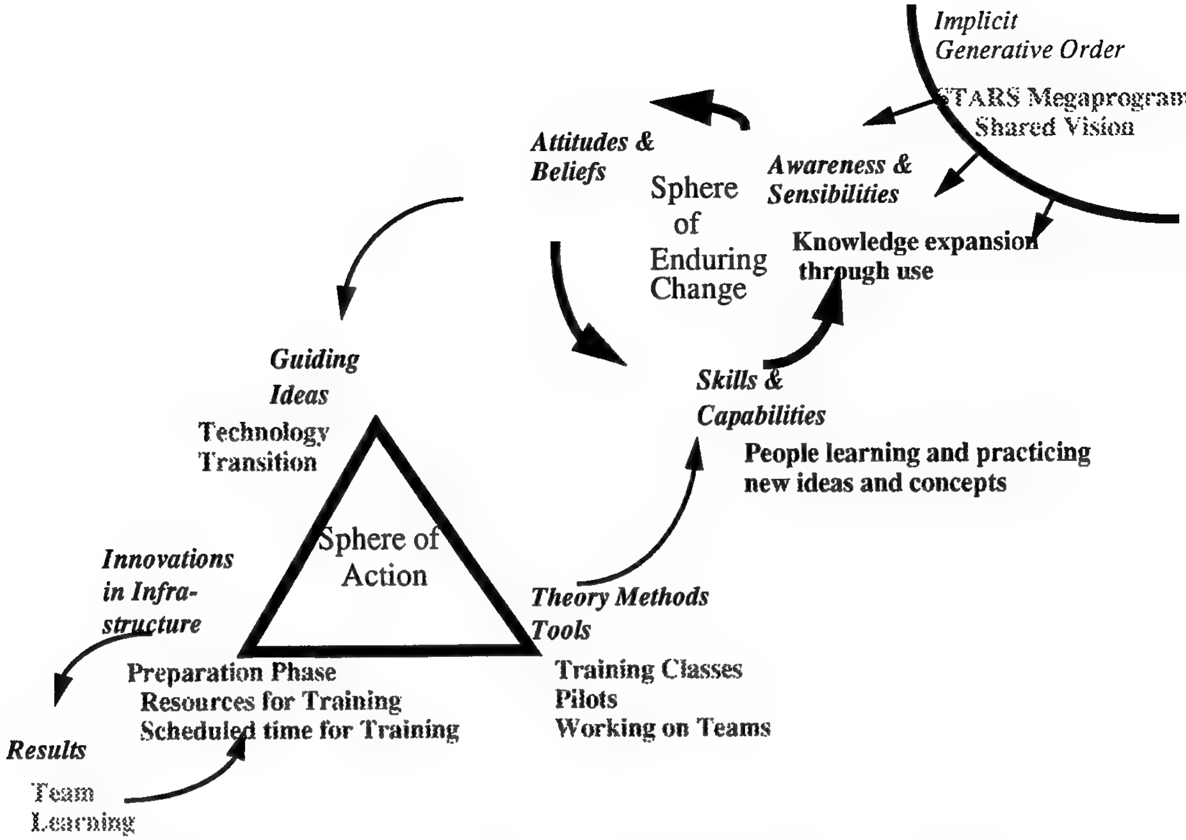

Figure 8. The SCAI Project and the Personal Mastery Discipline

Even though we are not sure that we can implement personal mastery as it is defined by Senge, we think projects can evaluate whether their organization is meeting the intent of this discipline by measuring project turnover, and by evaluating the kinds of jobs that people leaving the project, or their organization, are able to get as a result of the work they have done on the projects.

On the SCAI project for example, most contractor personnel have stayed with the project. Some of the Air Force personnel have extended their terms to work on the project, and at least two individuals who left obtained high paying jobs that utilized skills developed on the project. Other individuals, when leaving one project organization, joined another organization that allows them to stay with the project. This seems to indicate that, for the most part, people like working in this environment.

While a lot of time has been spent learning and adjusting to new technologies, and providing for growth in personal mastery on the SCAI project, more reflection is needed about how this transitioning of technology has shifted organizational attitudes and beliefs.

3.5 Systems Thinking

Systems thinking refers to a way of thinking about, and a language for describing and understanding the forces and interrelationships that shape the behavior of systems. This discipline helps us to see how to change systems more effectively, and how to act more in tune with the larger processes of the natural and economic world.

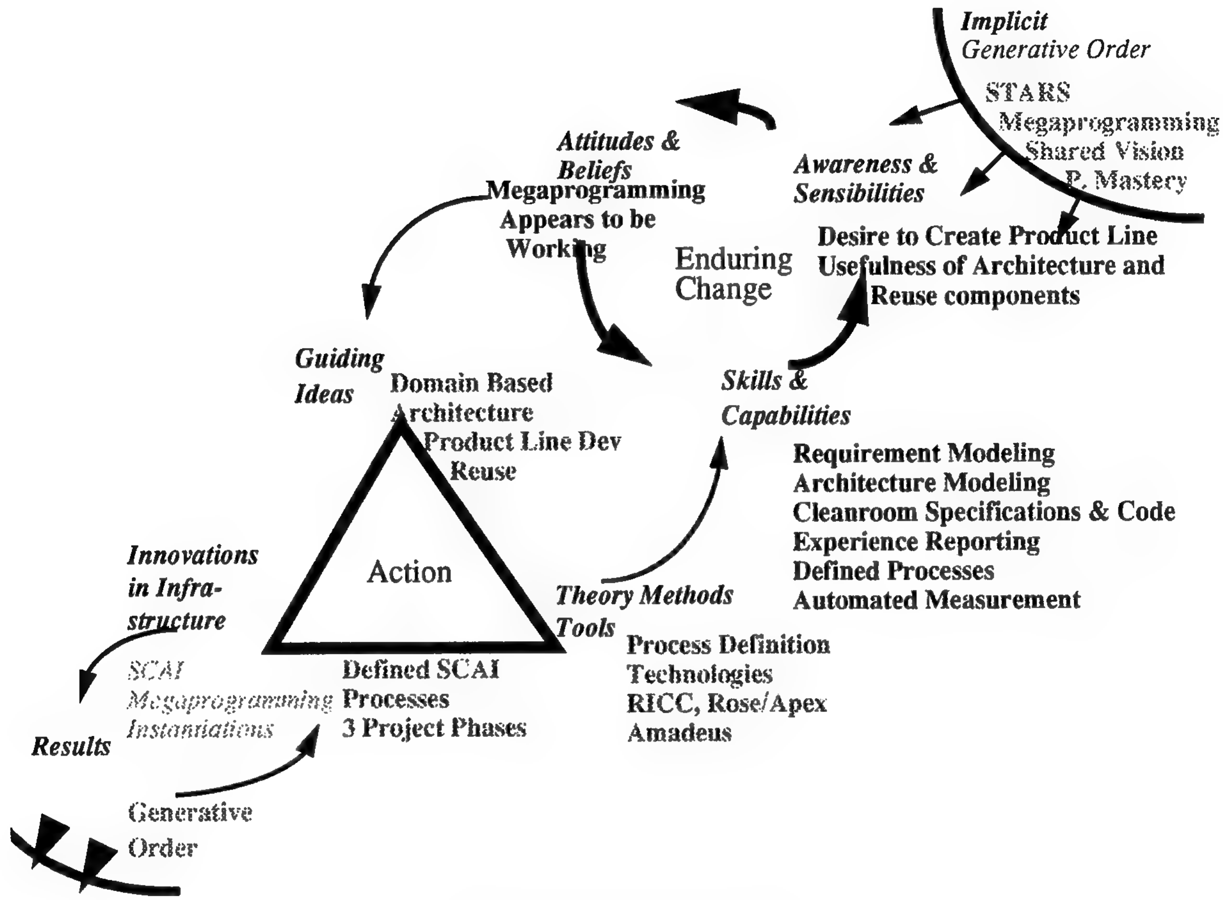

Figure 9. Systems Thinking

One of the guiding ideas that define megaprogramming, the idea of applying domain specific reuse, embodies practices of "systems thinking" to analyze problems in the domains of space, missile or air where it has been applied. This form of analysis requires the practitioners to utilize and enhance their personal mastery of the conceptualization capabilities characteristic of learning organizations. It has in turn impacted the way SCAI practitioners perceive of the organizational architecture required to support a product-line organization. For more information on these ideas, refer to another paper in these proceedings, "Space and Warning Systems Center Domain Experiences" by Brian Bulat.

Also, the concept of megaprogramming is an expression of system thinking. It provides a framework for simultaneous change in guiding ideas, innovations in infrastructure, and applying

new technologies. On the SCAI project, ideas of conceptualizing domains, creating product lines, and reusing, coupled with the definition and improvement of the DE/AE processes and the development of supporting technologies, (see Figure 9), have lead the SCAI organization into practicing the disciplines which initiate the deep learning characteristic of the Sphere of Enduring Change. The project has acquired new skills and capabilities, in modeling both requirements and architectures, using both object oriented analysis and the Ada Process Model structured analysis techniques. Cleanroom development practices have positively impacted code specification and development, and played a strong role in providing an environment that promotes teamwork. Process definition has given teams visibility into their actions and an ability to create improvements.

The project has become aware of their shared desires to create product line development environments. As demonstrated by the results depicted in Figure 3, Megaprogramming appears to be working. As indicated in Figure 9, and shown in other figures as well, the results produced as a consequence of all the actions taken in the Sphere of Action often serve as the "Implicit Generative Order" for a new cycle of organizational learning. It is believed that the successful SCAI releases will provide input into the Implicit Generative Order for other organizations transitioning to Megaprogramming technologies throughout the SWSC, just as the results of ARPA's work to develop Megaprogramming concepts and the SWSC and TRW C^2AI work provided input into the Implicit Generative Order, articulated as a Megaprogramming strategic intent for the SCAI project.

4.0 Conclusions

In conclusion the experience of the SCAI project demonstrates that when an organization have a strategic intent and they pay attention to the Sphere of Action, they are likely to active elements of the Sphere of Enduring Change and initiate the Deep Learning Cycle in their organization. In the spirit of the disciplines of organizational learning I will conclude with an inquiry, which is especially relevant to organizations that are interested in transitioning technologies. "If conscious attention is paid to practicing the five learning disciplines can the technology transitioning process be performed cheaper, better and faster?"

Sociology of Megaprogramming

Experiences in Generating an Organizational Learning Enterprise

Lynn Underhill

- Theory Background and Level Set
  - Evolution of Organization Models
  - Definition of Learning Organization Terms
  - Five Disciplines
  - Megaprogramming
  - Framework of a Learning Organization & Technology Transition
- SCAI Project Application of Theory
  - Overview of Project
  - SCAI Experiences with Five Disciplines
  - Conclusion

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Organization Models

AF/STARS SCAI

- **Machine**
  - Closed Systems
  - Bureaucratic and Hierarchical
  - Defined
  - Information Processes and Communicated according to Clearly defined Hierarchical Lines of Command

Defined by a set of relationships between clearly defined parts that operate in a deterministic order

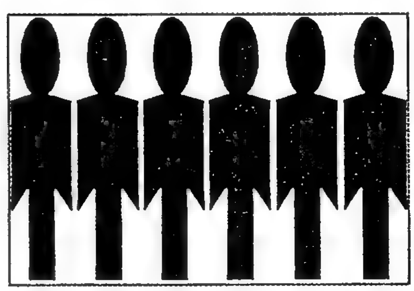
Gareth Morgan "Images of Organizations

LORAL Federal Systems

Organization Models

AF/STARS SCAI

- **Organisms**
  - Collaborative and Self-Referent
  - Display Cybernetic Characteristics of Single-loop Learning
    - » sense, monitor, scan environment
    - » relate environmental information to operating norms
    - » detect deviations from norms
    - » initiate corrective action



Defined by Relationship with a complex ecosystem where whole ecosystem is evolving

Gareth Morgan

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Organization Models

AF/STARS SCAI

- **Brain**
  - Holographic and Evolutionary
  - Inquisitive & Reflective
  - Display Characteristics of Double Loop Learning
    - » ability to question appropriateness of actions they decide to take

Defined by characteristics required in functioning of the whole are enfolded into the parts.
Gareth Morgan

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Five Disciplines

AF/STARS SCAI

- ***Shared Vision*** - Building shared images of the future
- ***Team Learning*** - Transforming conversation and collective thinking skills
- ***Mental Models*** - Reflecting, clarifying, and improving our internal pictures of the world, and seeing how they shape our actions and decisions.
- ***Personal Mastery*** - Expanding our personal capacity to create results
- ***Systems Thinking*** - Describing and understanding the forces and interrelationships that shape the behavior of systems .

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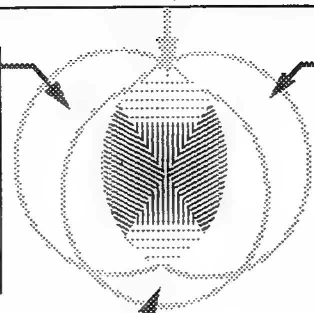
Megaprogramming

AF/STARS SCAI

VISION: Megaprogramming - An Emerging Paradigm
MISSION: Accelerate Transition to Megaprogramming
Goal: Faster, Better and Cheaper Software Development

Domain-Specific Reuse-Based

- Guided by reuse process.
- Based on application domain architecture
- Systems composed from reusable assets
- Assets include all life-cycle artifacts
- Supports continuous improvement in reuse processes and products



Process-Driven

- Guided by a defined process
  - developed from reusable process components
  - Adaptable to meet project goals
  - Promotes team work
- Supported by tools
- Supports continuous improvement in process and product

Technology Supported

- Process/Reuse Packaged in a SEE
- Based upon open architecture framework
- Adaptable approach for incorporating new technologies
- Continuous improvement in portability, adaptability reliability, and scalability

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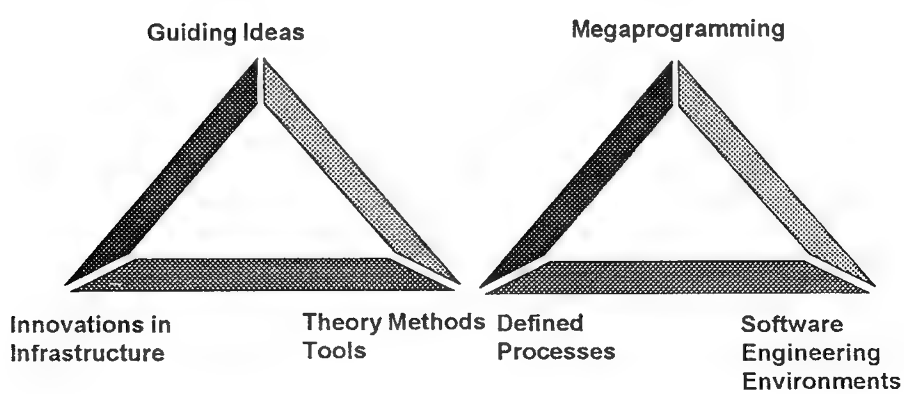
Architecture Mappings

AF/STARS SCAI



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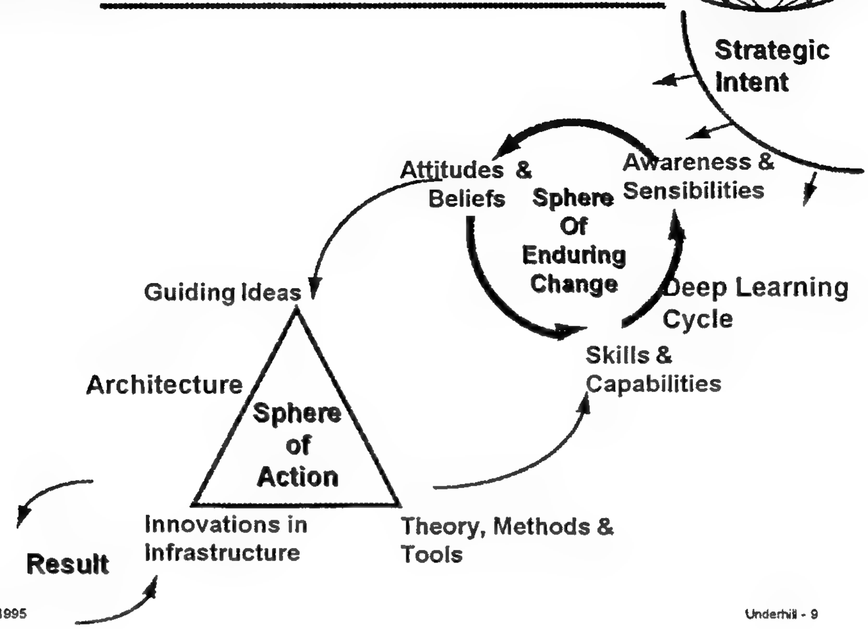
Organization Learning Framework



Learning Organization Framework

- Architecture
- Way we Work
  - Guiding Ideas - ideas which give values & direction to organization
  - Innovations in Infrastructure - means used to give employees the resources needed (to practice learning with context of their job)
  - Theory, Methods and Tools - Frameworks or means to pursue objectives and mechanisms to make, do or prepare with.

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Learning Organization Framework

AF/STARS SCAI

- Deep Learning Cycle
- Who We Are
  - Skills and Capabilities - Learning Organization skills include Aspiration, Reflection, Conversation and Conceptualization
  - New Awareness and Sensibilities - As disciplines and skills are practiced new views and behaviors arise
  - New Attitudes and Beliefs - Represents changes at the deepest levels of an organization

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Inquiry

AF/STARS SCAI

- If Conscious Attention is Paid to the Practice of the Five Learning Disciplines, Can the Technology Transition Process be Performed Cheaper, Better and Faster?

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SCAI History

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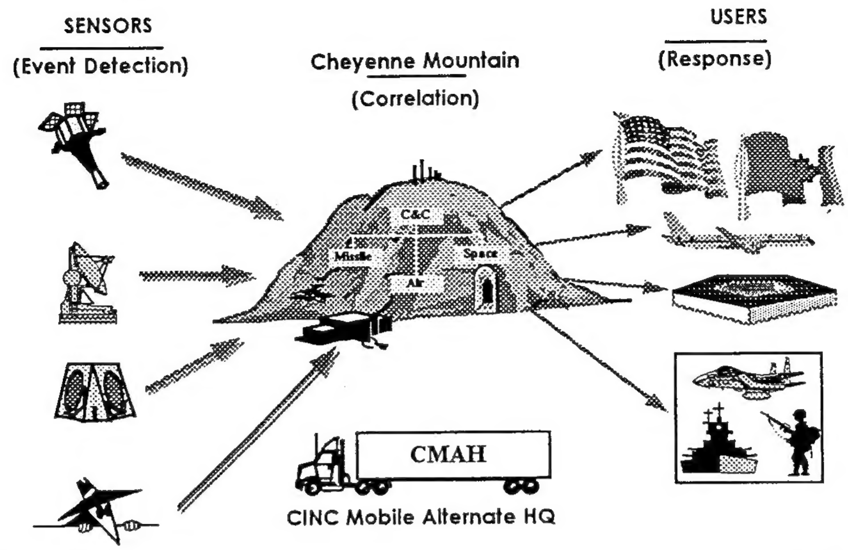

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SCAI Results

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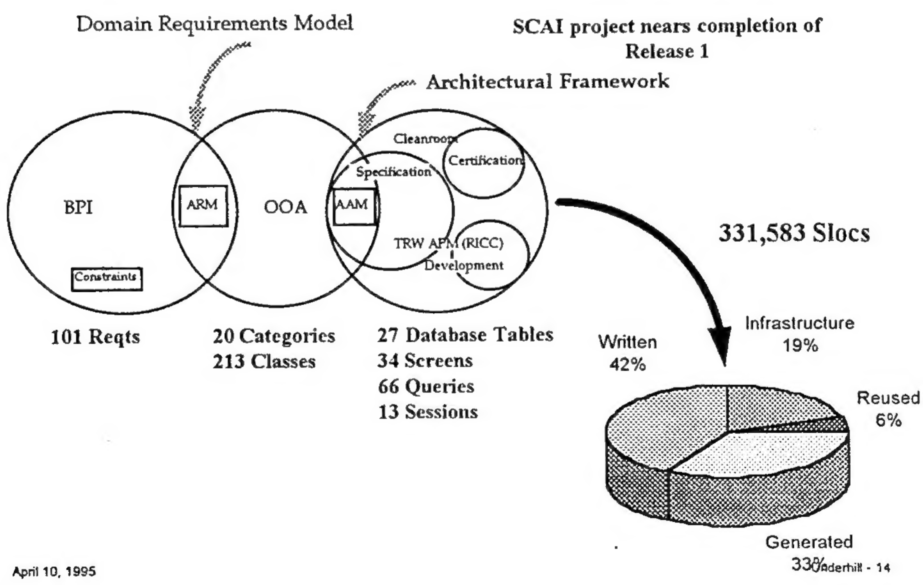

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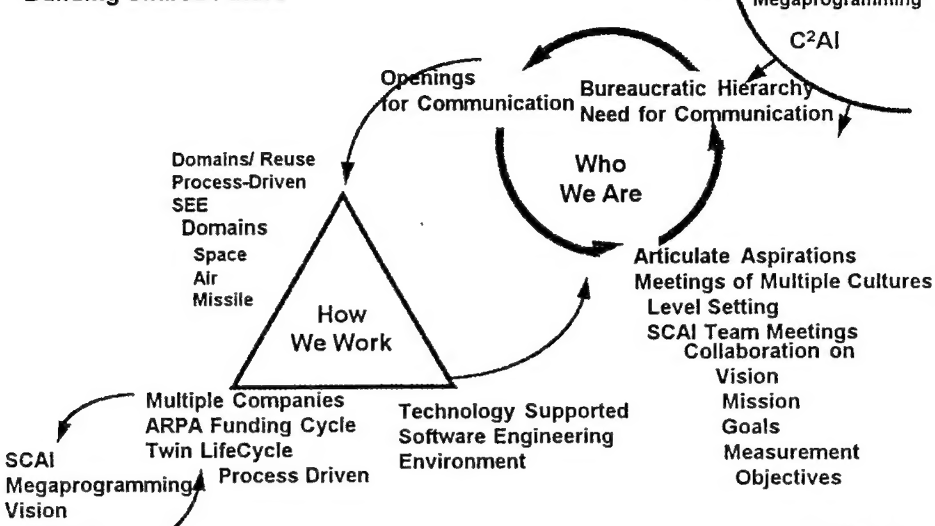
Shared Vision

AF/STARS SCAI

Building Shared Future



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Team Learning

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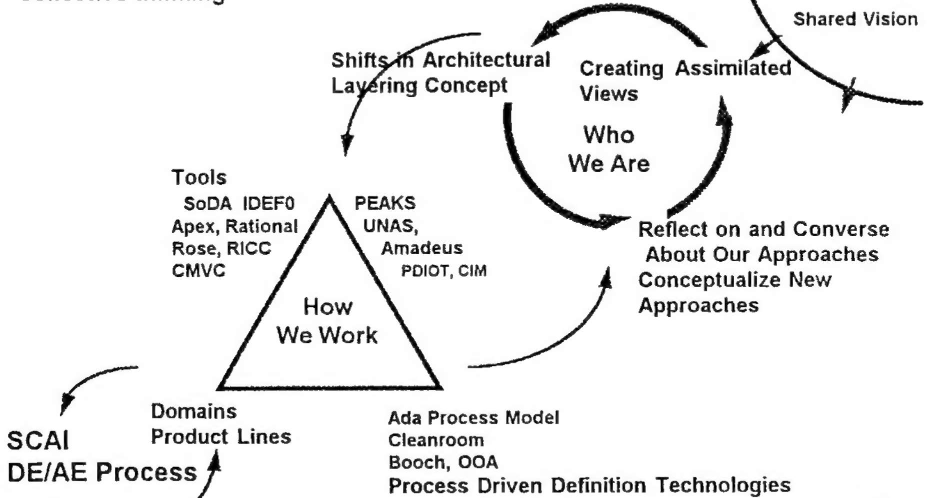
Transforming conversation & collective thinking



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Mental Models

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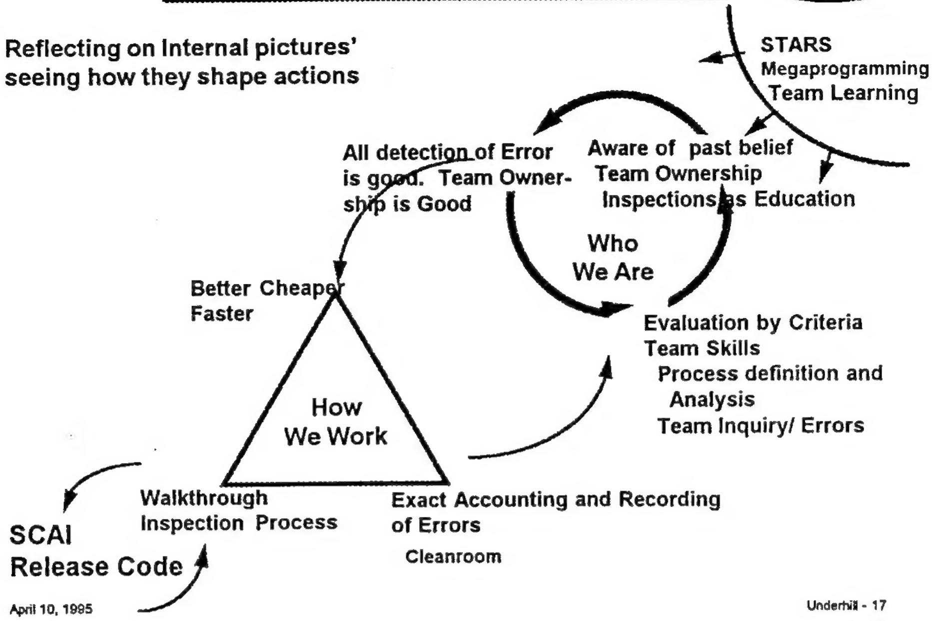
Reflecting on Internal pictures' seeing how they shape actions



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Personal Mastery

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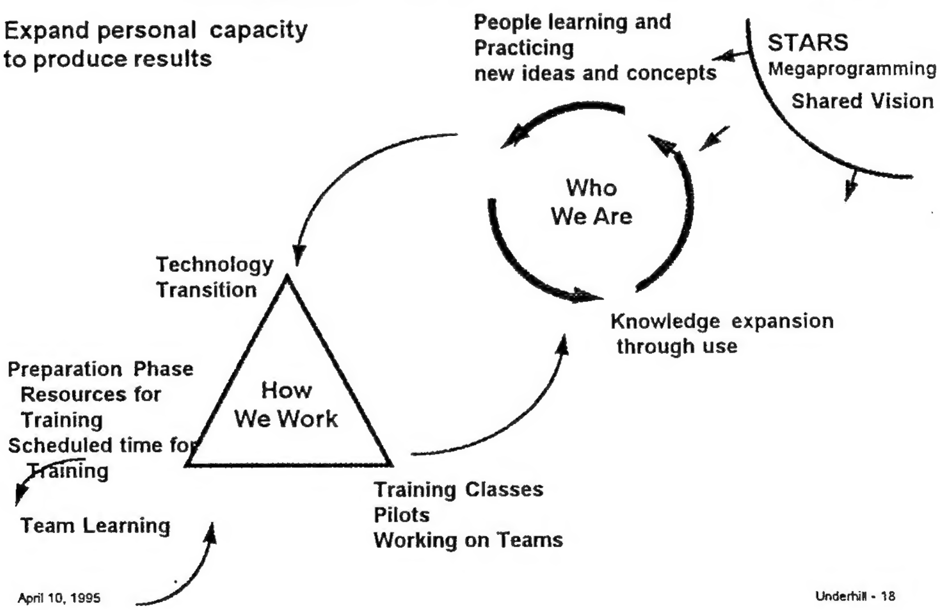
Expand personal capacity to produce results



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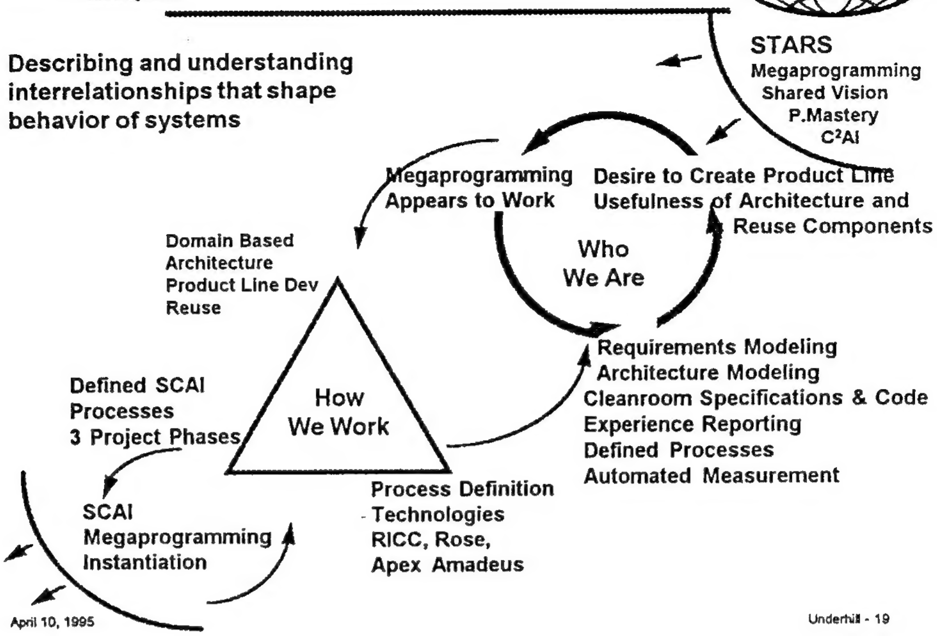
Systems Thinking

AF/STARS SCAI

Describing and understanding interrelationships that shape behavior of systems



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Conclusion

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- If Conscious Attention is Paid to the Practice of the Five Learning Disciplines, Can the Technology Transition Process be Performed Faster Better and Cheaper?

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